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National Aerospace Laboratory NLR



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## **The instrumentation for the ESA parafoil technology demonstrator test**

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## **Abstract**

The Parafoil Technology Demonstrator (PTD) programme was set up to demonstrate the feasibility to guide and control a large scale parafoil autonomously to a predefined point and to perform a flared landing within a specified range. Another objective was to enable further investigation into the flight dynamics of parafoil systems.

The program was conducted under the responsibility of the European Space Agency and carried out by DASA Ottobrunn. As a subcontractor Fokker Space was responsible for the design of the electrical architecture of the Parafoil Technology Demonstrator Test Vehicle (PTTV). The National Aerospace Laboratory of The Netherlands NLR contributed to this design by developing a significant part of the instrumentation for the PTTV.

The instrumentation consisted of various sensors of which the data was collected by a data acquisition system. The data acquisition system distributed the data to other subsystems like a data recorder, telemetry system and an on-board computer system. This computer system primarily took care of the Guidance, Navigation and Control (GNC) function of the PTTV and for this purpose it controlled the trailing edge deflection of the parafoil by providing data to an actuator system.

To perform the unique task for the PTTV the instrumentation was designed using well known equipment and techniques from the flight test instrumentation NLR recently used in aircraft flight test programmes. This way it was possible to deal with the relative short development time combined with the requirements regarding reliability under severe environmental conditions. The suitability of the concept for the PTTV instrumentation was affirmed during a flight test programme, which consisted of four flights in total.

This paper will mainly focus on the requirements, design and performance of the instrumentation system of the PTTV. In addition some attention is paid to the overall system architecture and the conducted flight test programme.



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## **1 Introduction**

In 1994 the European Space Agency (ESA) initiated the Parafoil Technology Demonstrator (PTD) project. The main objective of the project was to study the performance of flights with large scale parafoil/payload systems and the demonstration of a reasonable flight envelope in which a required level of reliability and safety for future manned space transportation systems can be achieved [Ref. 1]. The flights finally had to be performed autonomously guided and controlled.

The PTD project was conducted by Daimler-Benz Aerospace (DASA) as the prime contractor. The programme was set up using a large scale Parafoil Test Vehicle (PTTV) consisting of a parafoil of 160 m<sup>2</sup> and a payload with a total weight varying from 1800 to 3200 kg. Part of the payload was an instrumentation system to perform the required Guidance, Navigation and Control (GNC) functions of the PTTV. The planned demonstration consisted of several droppings of the PTTV from a carrier aircraft at altitudes ranging from 1.4 to 4 km.

As a subcontractor Fokker Space was responsible for the design of the electrical architecture of the PTTV. The National Aerospace Laboratory NLR contributed to this design and implementation by developing a significant part of the instrumentation.

## 2 Electrical architecture of the PTTV

The general electrical architecture of the PTTV [Ref. 2] is depicted in figure 1. The central unit in the system is the Guidance, Navigation and Control Computer (GNCC). The GNCC receives information from the sensor systems via the Data Acquisition System (DAS). Based on this information the GNCC provides steering signals to an actuator system, which controls the trailing edge deflection of the parafoil. To close the control loop the actual actuator position data is fed back into the GNCC.

The output of the DAS is transmitted to a ground station to monitor the descent of the PTTV. In addition a video signal of a camera installed on top of the payload, looking upwards to the parafoil, is also transmitted to the ground to monitor the behaviour of the parafoil. A solid state recorder stores the measured and processed data for off-line processing purposes, e.g. aerodynamic model identification. Via a telemetry up-link it was possible to send commands to the GNCC and to manually take over control of the PTTV. For safety reasons this last function was duplicated via a redundant telemetry link. In case of severe problems an emergency sequence could be initiated via either one of these two up-links.

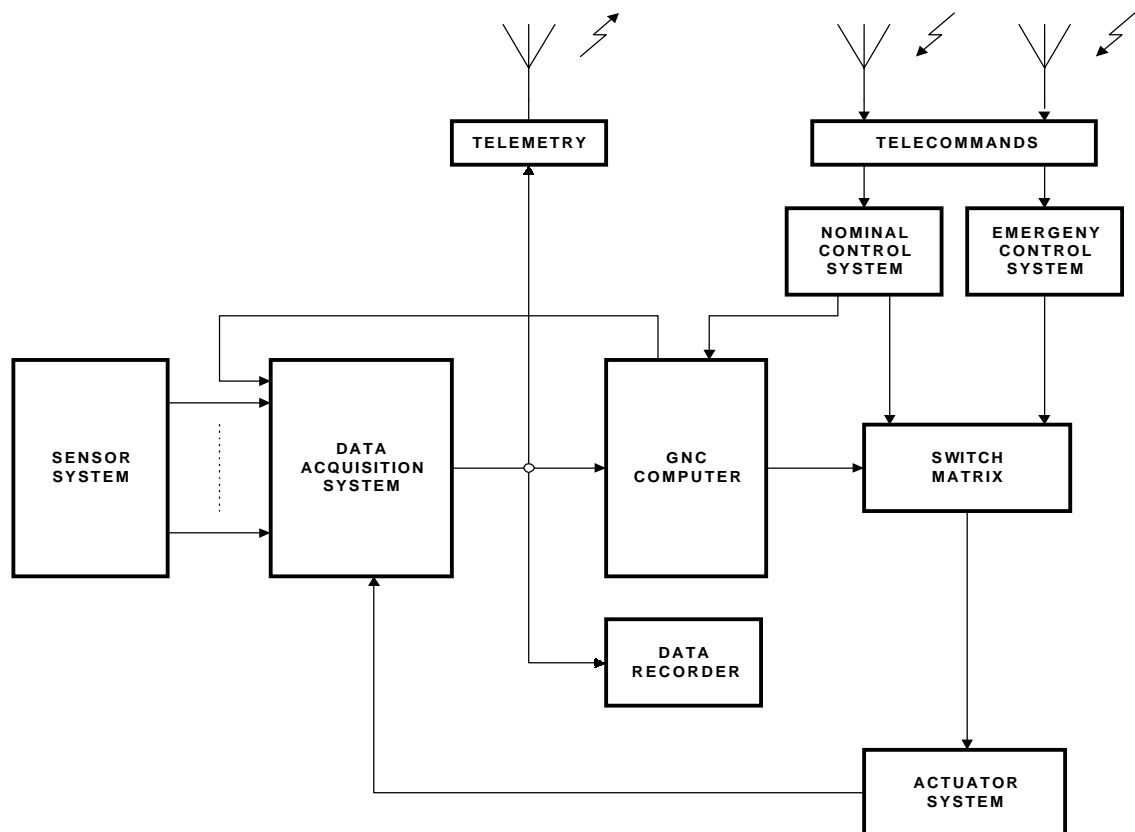


Fig. 1 General electrical architecture of the PTTV

### 3 Instrumentation requirements

The main purpose of the instrumentation was to acquire the input data for the GNCC of the PTTV. Table 1 summarises the requirements for the key parameters. In addition to the parameters required to implement the GNC functions, several parameters had to be added for evaluation and ‘house keeping’ purposes, such as air temperatures, barometric pressure, shock (main structure and instrumentation rack), battery voltages and status information from the PTTV subsystems.

It was stated that commonly available equipment had to be used as much as possible in order to prevent the development of special equipment. However, the equipment also had to meet the specific requirements with regard to the environmental conditions, especially shock conditions, which were specified to be below 5 g in all phases of the flight, including deployment and landing.

Table 1: Requirements for PTTV key parameters

Parameter		Unit	Range	Accuracy
Position	latitude	deg	-90 / 90	5 m
	longitude	deg	-180 / 180	5 m
	altitude (geometric)	m	-2000 / 2000	10 m
	ground track	deg	0 / 360	1
	distance to ground	m	0 / 100	0.1
Speed	horizontal, vertical	m/s	0 / 40	0.05
Acceleration	x, y	m/s <sup>2</sup>	-20 / 20	0.02
	z	m/s <sup>2</sup>	-10 / 30	0.02
Attitude	pitch	deg	-90 / 90	0.5
	roll	deg	-180 / 180	0.5
	heading	deg	0 / 360	0.5
Angular rate	roll	deg/s	-50 / 50	0.01
	pitch, yaw	deg/s	-30 / 30	0.01
Airflow	speed	m/s	0 / 40	0.4
	angle of attack	deg	-20 / 20	0.4
	angle of side slip	deg	-10 / 10	0.4
Actuator position	left, right	m	0 / 2.5	0.025

#### **4 Sensor selection**

A Differential Global Positioning System (DGPS) was used as the primary navigation source, providing the latitude, longitude, geometric altitude, horizontal and vertical velocity and the ground track angle of the PTTV. The system consisted of two Novatel OEM 2100 receivers; one in the PTTV and one in the ground station located on an accurately known position at the test site. The calculated position error of the receiver at the ground station was transmitted to the PTTV and used as a correction to the position given by the airborne receiver. In this way absolute position accuracy could be achieved in real-time of 2 meter (optimum performance) to 5 meter under worst case conditions.

The distance to ground had to be measured with an accuracy better than 0.1 meter to initiate the flare manoeuvre of the parafoil at the right moment. This requirement could not be met using standard radar altimeters. Instead a Laser Distance Meter (Jenaoptik LEM 300-W) was selected. Tests with this sensor, including a flight test in one of the NLR research aircraft, proved that it was possible to meet the requirement under dynamic flight conditions.

The accelerations of the PTTV were measured using a Tri-axial Accelerometer System, the so called STAS-package, which contains three Sundstrand QA-1200 Servo Accelerometer. This type of accelerometer consists of a self-contained servomechanism with a seismic element and the servo electronics.

To obtain the attitude, heading and angular rates of the PTTV a strap down inertial reference system was used. The Litef LCR-92, a fiber optic gyro based Attitude and Heading Reference System (AHRS), was selected for this purpose. To obtain the initial heading information a magnetic flux valve, mounted on the payload structure, was connected to the AHRS.

To obtain airflow data a 5-hole probe was installed on an extendable boom with a total length of approximately 2.5 meter to be clear of the turbulence area of the PTTV. The pressure distribution of the probe was measured with four sensitive differential pressure transducers. From this pressure distribution in the ground station the relative wind velocity, the angle of attack and the angle of sideslip were calculated. Prior to the installation the coefficients for the calculations were determined through wind tunnel tests.

All selected sensors, except for the Laser Distance Meter, were off-the-shelf components at NLR, which were already used successfully in recent flight or windtunnel test programmes. This considerably reduced the instrumentation development time and technical risk.



## **5 Data Acquisition System**

The Data Acquisition System (DAS) is another example how existing and commonly available components for flight test instrumentation were used in the design of the PTTV instrumentation. The DAS consisted of two units, a Remote Multiplexer Digitizer Unit (RMDU) and a Pre-Sample Filter Unit (PSFU), both made by Teledyne Controls, used in many flight test programmes before.

Since most of the sensors delivered a digital output format, according to either ARINC-429 or RS-232, these signals were connected directly to the RMDU. The analog signals, e.g. from the STAS and pressure sensors, required adequate filtering prior to digitising to avoid aliasing errors during signal reconstruction. These signals were connected to the RMDU via the PSFU, which contained a filter and amplifier board optimised for each input signal.

The RMDU scanned all input channels at a pre-defined frequency, digitises the analog channels and outputs the digital data in a serial data stream to GNCC, data recorder and telemetry transmitter. The RMDU internally inserted time code information and various housekeeping data into the data stream.



## **6 Guidance, Navigation and Control Computer**

The Guidance, Navigation and Control Computer (GNCC) was a NLR developed airborne VME based computer system, which was used before in instrumentation systems for production test flights of Fokker aircraft. The GNCC comprises of a 68040 processor board, running at 25 MHz and an IRIG-PCM input board. The latter board is used to input the data stream from the DAS. Via serial ports the GNCC communicated with the other PTTV sub-systems, the telemetry receiver and the actuator system. A terminal port enabled to enter mission related coefficients prior to the test flight of the PTTV.

The software for the GNCC consisted of two main modules, the Basic Software module (BSW) and the Application Software module (ASW). The BSW module, which was developed by NLR, contained the real-time operating system, scheduler and the drivers to communicate with the peripherals. It also included routines to convert the raw PCM data from the DAS into engineering units.

The ASW module, which was developed by DASA and Dassault Aviation, performed the Guidance, Navigation and Control functions [Ref. 3]. It operated in either one of two modes: an autonomous mode and a remote mode. In the autonomous mode the GNCC calculated steering commands based upon the sensor input data and as a results it issued the appropriate commands to the actuator system. In the remote mode the GNCC provides the actuator system with the commands as received via the telemetry tele-command link.

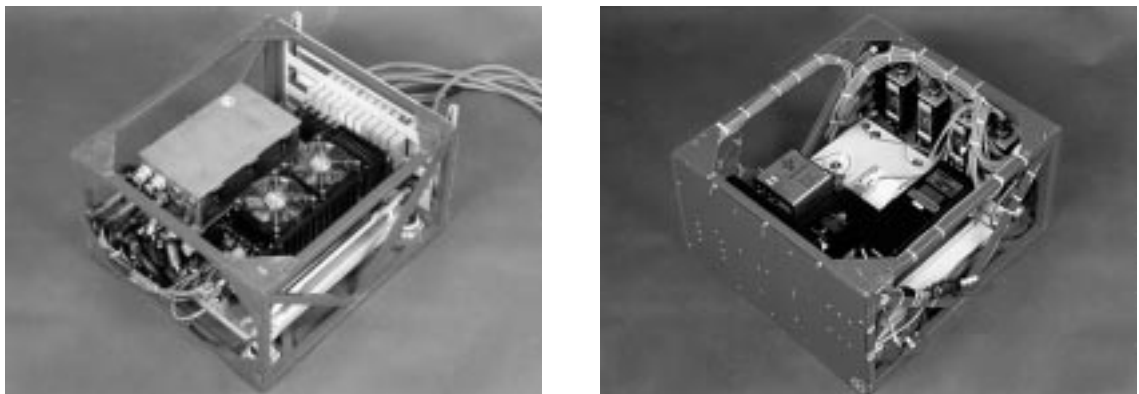
The data transfer between the BSW and ASW modules took place via predefined service calls. A sequencer function in the BSW module provided the timing for the various tasks.

## 7 Mechanical lay-out

The instrumentation was mounted into two standard modular steel framed instrumentation racks with the outline dimensions of 0.58 x 0.53 x 0.32 m. One rack housed the GNCC and DAS, which for that purpose was equipped with a mounting frame with additional vibration and shock damping devices.

The other rack housed most of the sensors. Because mechanical alignment of the accelerometers and AHRS was important for the system accuracy they were hard mounted on a special transducer platform, which offered facilities to align the axis of the platform with the body axis of the PTTV.

Both racks had a connector panel for easy interconnection between the two racks and connection the other PTTV sub-systems.



*Fig. 2 The instrumentation racks for GNCC/DAS and the transducers*

The total weight of the instrumentation package was approximately 200 kg. This was a significant contribution (app. 10%) to the total weight of the payload and the major disadvantage of the use of off-the-shelf equipment, which mainly originated from the flight test instrumentation for civil type of aircraft.

## 8 The flight test programme

The main objective for the flight tests with the PTTV was the analysis of the steady and dynamic flight performance and stability of the entire parafoil/payload combination during all phases of the flight and under different conditions.

Prior to the real test flights a check out flight with the payload mounted under a helicopter was carried out. During this flight the data integrity of the sensors data and the performance of the data links between the PTTV and ground station were proved.

The actual flight tests were carried out at the military training area in Jägerbrück, Germany, which offered a safety area of about 8 by 8 km and a treeless zone of about 6 by 2 km.

In the period from April to June 1997 four droppings of the PTTV from a Transall C 160 aircraft took place. The first three flights were conducted from a dropping altitude of approximately 1500 meter. During these flights the GNCC was active, however the PTTV was remotely controlled from the ground station. As a result of the first two flights adaptations to the steering mechanism of the parafoil had to be made, which proved to be successful during the third flight.

Due to the weather conditions the planned dropping altitude of 3000 meter for the fourth flight was restricted to 1700 meter. During this last flight the PTTV was autonomously guided within 200 m of the preselected landing spot by the GNCC. The landing flare procedure was performed under remote control.

From the flight test results it was concluded that a well functioning and reliable test vehicle was available, however it was recognised that for the study on the dynamic behaviour significantly more flight tests have to be performed.



*Fig. 3 PTTV after the flight*



## **9 Conclusion**

The instrumentation system, including transducers and on-board computer system, was based upon available equipment for flight testing of civil and military aircraft. Using this well-proven equipment the developmental and financial risks were minimised at the expense of a sub optimal, but acceptable solution concerning volume and weight. After the four test flights it was concluded that the instrumentation performed well to its specification.

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